

Imprints of CP violation asymmetries in rare $\Lambda_b \rightarrow \Lambda \ell^+ \ell^-$ decay in family non-universal Z' model

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(Dated: August 20, 2014)

We investigate the exclusive rare baryonic $\Lambda_b \rightarrow \Lambda \ell^+ \ell^-$ in a family non-universal Z' model, which is one of the natural extension of standard model. Using transition form factors, calculated in the framework of light cone QCD sum rules, we analyze the effects of polarized and unpolarized CP violation asymmetries for the said decay. Our results indicate that the value of unpolarized and polarized CP-violation asymmetries are considerable in both $\Lambda_b \rightarrow \Lambda \mu^+ \mu^-$ and $\Lambda_b \rightarrow \Lambda \tau^+ \tau^-$ channels and hence they give clear indication of new physics arising from the neutral Z' gauge boson. It is hoped that the measurements of these CP-violating asymmetries will not only help us to relate new physics, but also help us to determine the precise values of the parameters of new gauge boson Z' .

I. INTRODUCTION

Despite the discovery of the last missing chunk of the Standard Model (SM), the Higgs boson, and its phenomenological success, there are hints that leads to new physics (NP). The flavour sector is one of the key area which comes in these paths. Because of the joint efforts at the hadron colliders and at the B factories which provided us with data of unprecedented precision in this sector, which are not sensitive to small effects in theoretical calculations that are essential in comparison with the experimental measurements and to see if there are any hints of the NP.

There are two approaches which are mainly considered to investigate physics beyond the Standard model. The first approach is the direct search of new particles, where to produce the particles corresponding to different NP models, the most alluring in this class are different supersymmetric models, the energy of the colliders is raised. The second approach is the indirect search, i.e. to increase the experimental precision on the data of different SM processes where NP effects can manifest themselves. The focus of the two major detectors ATLAS and CMS experiments at the Large Hadron Collider (LHC) at CERN is to detect the possible new particles produced at sufficiently large energy. However, in the indirect searches, flavour physics plays an important role to investigate physics within and beyond the SM, and the experiment which represents the precision frontier are the LHCb at LHC, the Belle II at the super KEKB and different planned super-B factories will join this arena in future.

In the precision approach, the processes that are suitable to investigate physics within and beyond the SM are the rare decays, particularly the decays which are described by the $b \rightarrow s(d)$ transitions. The attractive feature of such kind of decays is that they are not allowed at tree level in the SM and possible only at loop level [1]. Therefore, these decays serve as an excellent candidates to chalk out the status of new physics beyond the SM. In mesonic sector, rare decays of B mesons has been widely studied both theoretically and experimentally in detail [2, 3].

It is well known that the predications of the SM results are in good agreement with the current experimental data, however there are still unanswered questions in this elegant model, e.g. CP violation, hierarchy puzzle, neutrino oscillations, the few to name. To answer these questions a large number of NP models such as extra dimension models, different versions of supersymmetric models, etc exist in literature and the extensive studies on the exclusive semileptonic decays of B mesons and Λ_b baryonic decays both has also been made [4–9].

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In grand unified theories such as $SU(5)$ or string inspired E_6 models [10–14], one of the most relevant is the Z' scenarios that include the family non-universal Z' [15, 16] and leptophobic Z' models [17, 18]. Experimental searches of an extra Z' boson is an important task of the Tevatron [19] and LHC [20] experiments. On the other hand to get the constraints on the Z' gauge boson couplings through low energy processes are crucial and complementary for direct searches $Z' \rightarrow e^+e^-$ at Tevatron [21]. The most interesting thing about the family non universal Z' model is the new CP-violating phase which have large effects on many FCNC processes [16, 22], such as $B_s - \bar{B}_s$ mixing [23–27], and rare hadronic B -meson decays [28–30].

In baryonic sector exclusive $\Lambda_b \rightarrow \Lambda \ell^+ \ell^-$ decays, at quark level are described by $b \rightarrow s \ell^+ \ell^-$ transition. The main difference between these and other mesonic decays are that they can give information about the helicity structure of the effective Hamiltonian for the FCNC $b \rightarrow s$ process in the SM and beyond [31]. On the experimental side, first observation on rare baryonic $\Lambda_b \rightarrow \Lambda \mu^+ \mu^-$ decay has been observed by CDF Collaboration [32], and recently this decay was also studied by LHCb collaboration [33]. The experimental investigation motivates theoreticians to do more deep analysis of the different physical observables such as branching ratio, forward backward asymmetry, single and double lepton polarization asymmetries and CP violation asymmetry in the these decay modes. It will be hoped that such studies are useful to distinguish various extensions of the SM.

In the present work, we analyze the effects of polarized and unpolarized CP violation asymmetries for $\Lambda_b \rightarrow \Lambda \ell^+ \ell^-$ decay in the family non universal Z' model developed in [16]. From the CP violation asymmetry view point it is important to emphasize here that $b \rightarrow s$ transition matrix elements are proportional to three quark coupling matrix elements usually called CKM matrix elements, $V_{tb}V_{ts}^*, V_{cb}V_{cs}^*$ and $V_{ub}V_{us}^*$; however due to the unitarity condition, and neglecting the matrix elements $V_{ub}V_{us}^*$ in comparison with $V_{tb}V_{ts}^*$ and $V_{cb}V_{cs}^*$ the CP asymmetry is highly suppressed in the SM. Therefore, the measurements of CP violating asymmetries in $b \rightarrow s$ decays play an important role to find the imprints of the Z' model.

The structure of the paper is as follows. In section II we develop a theoretical tool box in which we present the effective Hamiltonian for the decay $b \rightarrow s \ell^+ \ell^-$. In the same section we present the transition matrix element for the decay $\Lambda_b \rightarrow \Lambda \ell^+ \ell^-$ decay, and the expressions for unpolarized and polarized CP violation for the said decay in family non-universal Z' model. In Section III we discuss the numerical results of the said physical observables. The concluding remarks are also presented in the same section.

II. THEORETICAL TOOL BOX

At quark level the decay $\Lambda_b \rightarrow \Lambda \ell^+ \ell^-$ ($\ell = \mu, \tau$) is governed by the transition $b \rightarrow s \ell^+ \ell^-$, the effective Hamiltonian for such kind of decays at $O(m_b)$ scale can be written as

$$H_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \sum_{i=1}^{10} C_i(\mu) O_i(\mu) \quad (1)$$

where G_F is Fermi coupling constant and V_{ij} are the matrix elements of the CKM matrix. In Eq. (1), $O_i(\mu)$ are the local quark operators and $C_i(\mu)$ are the corresponding Wilson coefficients at energy scale μ . The explicit expressions for of the Wilson coefficients at next to leading logarithm order and next to next leading logarithm are given in ref [34–43]. The operators responsible for such kind of decays are O_7 , O_9 and O_{10} which are summarized in [7]. In terms of the effective Hamiltonian given in Eq. (1), the quark level amplitude for the said decay in the SM can be written as

$$\begin{aligned} \mathcal{M}^{SM}(b \rightarrow s \ell^+ \ell^-) = & -\frac{G_F \alpha}{\sqrt{2}\pi} V_{tb}V_{ts}^* \left\{ C_9^{eff} (\bar{s} \gamma_\mu L b) (\bar{\ell} \gamma^\mu \ell) \right. \\ & \left. + C_{10}^{SM} (\bar{s} \gamma_\mu L b) (\bar{\ell} \gamma^\mu \gamma_5 \ell) - 2m_b C_7^{eff} (\bar{s} i \sigma_{\mu\nu} \frac{q^\nu}{q^2} R b) (\bar{\ell} \gamma^\mu \ell) \right\}, \end{aligned} \quad (2)$$

where q^2 is the square of the momentum transfer and α is the fine structure constant.

A family non-universal Z' boson could be derived naturally in many extensions of the SM, the most economical way to get it is to include an additional $U'(1)$ gauge symmetry. This model has been formulated in detail by Langacker and Plümacher [16]. In a family non-universal Z' model, FCNC transitions $b \rightarrow s \ell^+ \ell^-$ could be induced at tree level because of the non-diagonal chiral coupling matrix. Assuming that the couplings of right handed quark flavors with Z' boson are diagonal and ignoring $Z - Z'$ mixing, the effective Hamiltonian of Z' part for the decay $b \rightarrow s \ell^+ \ell^-$ can be written as [44–46]

$$\mathcal{H}_{eff}^{Z'}(b \rightarrow s \ell^+ \ell^-) = -\frac{2G_F}{\sqrt{2}} V_{tb}V_{ts}^* \left[-\frac{B_{sb}^L B_{\ell\ell}^L}{V_{tb}V_{ts}^*} (\bar{s} b)_{V-A} (\bar{\ell} \ell)_{V-A} - \frac{B_{sb}^L B_{\ell\ell}^R}{V_{tb}V_{ts}^*} (\bar{s} b)_{V-A} (\bar{\ell} \ell)_{V+A} \right]. \quad (3)$$

One can also write Eq. (3) in the following way

$$\mathcal{H}_{eff}^{Z'}(b \rightarrow s\ell^+\ell^-) = -\frac{4G_F}{\sqrt{2}}V_{tb}V_{ts}^* \left[\Lambda_{sb}C_9^{Z'}O_9 + \Lambda_{sb}C_{10}^{Z'}O_{10} \right], \quad (4)$$

where

$$\Lambda_{sb} = \frac{4\pi e^{-i\phi_{sb}}}{\alpha_{EM}V_{tb}V_{ts}^*} \quad (5)$$

$$C_9^{Z'} = |\mathcal{B}_{sb}|S_{LL}|; \quad C_{10}^{Z'} = |\mathcal{B}_{sb}|D_{LL}|, \quad (6)$$

and

$$\begin{aligned} S_{\ell\ell}^{LR} &= B_{\ell\ell}^L + B_{\ell\ell}^R, \\ D_{\ell\ell}^{LR} &= B_{\ell\ell}^L - B_{\ell\ell}^R. \end{aligned} \quad (7)$$

The most economical feature of the family non-universal Z' -model is that operator basis remains the same as in the SM and the only modifications come are in the Wilson coefficients, where C_9 and C_{10} get modification while the Wilson coefficient C_7^{eff} remains unchanged.

The total amplitude for the decay $\Lambda_b \rightarrow \Lambda\ell^+\ell^-$ is the sum of SM and Z' contribution, and can be written as follows

$$\begin{aligned} \mathcal{M}^{tot}(\Lambda_b \rightarrow \Lambda\ell^+\ell^-) &= -\frac{G_F\alpha}{2\sqrt{2}\pi}V_{tb}V_{ts}^*[\langle\Lambda(k)|\bar{s}\gamma_\mu(1-\gamma_5)b|\Lambda_b(p)\rangle\{C_9^{tot}(\bar{\ell}\gamma^\mu\ell) + C_{10}^{tot}(\bar{\ell}\gamma^\mu\gamma^5\ell)\} \\ &\quad -\frac{2m_b}{q^2}C_7^{eff}\langle\Lambda(k)|\bar{s}i\sigma_{\mu\nu}q^\nu(1+\gamma^5)b|\Lambda_b(p)\rangle\bar{\ell}\gamma^\mu\ell], \end{aligned} \quad (8)$$

where $C_9^{tot} = C_9^{eff} + \Lambda_{sb}C_9^{Z'}$ and $C_{10}^{tot} = C_{10}^{SM} + \Lambda_{sb}C_{10}^{Z'}$

The matrix elements for the decay $\Lambda_b \rightarrow \Lambda\ell^+\ell^-$ can be straightforwardly parameterized in terms of the form factors as follows[47]

$$\begin{aligned} \langle\Lambda(k)|\bar{s}\gamma_\mu(1-\gamma_5)b|\Lambda_b(p)\rangle &= \bar{u}_{\Lambda(k)}[f_1(q^2)\gamma_\mu + i\sigma_{\mu\nu}q^\nu f_2(q^2) + q^\mu f_3(q^2) - \gamma_\mu\gamma_5 g_1(q^2) \\ &\quad - i\sigma_{\mu\nu}q^\nu\gamma_5 g_2(q^2) - q^\mu\gamma_5 g_3(q^2)]u_{\Lambda_b(p)}, \end{aligned} \quad (9)$$

$$\begin{aligned} \langle\Lambda(k)|\bar{s}i\sigma^{\mu\nu}q^\nu(1+\gamma_5)b|\Lambda_b(p)\rangle &= \bar{u}_{\Lambda(k)}[f_1^T(q^2)\gamma_\mu + i\sigma_{\mu\nu}q^\nu f_2^T(q^2) + q^\mu f_3^T(q^2) + \gamma_\mu\gamma_5 g_1^T(q^2) \\ &\quad + i\sigma_{\mu\nu}q^\nu\gamma_5 g_2^T(q^2) + q^\mu\gamma_5 g_3^T(q^2)]u_{\Lambda_b(p)}, \end{aligned} \quad (10)$$

where f_i, g_i and f_i^T, g_i^T are the transition form factors for the decay $\Lambda_b \rightarrow \Lambda$.

By using the matrix elements which are parameterized in terms of transition form factors [Eqs.(9) and (10)] with expression (8), the decay amplitude for the decay $\Lambda_b \rightarrow \Lambda\ell^+\ell^-$ can be written as

$$\mathcal{M}^{tot}(\Lambda_b \rightarrow \Lambda\ell^+\ell^-) = \frac{G_F\alpha_{EM}}{2\sqrt{2}\pi}V_{tb}V_{ts}^* [\bar{u}_{\Lambda(k)} \{ \tau_\mu^1(\bar{\ell}\gamma^\mu\ell) + \tau_\mu^2(\bar{\ell}\gamma^\mu\gamma^5\ell) \} u_{\Lambda_b(p)}] \quad (11)$$

The hadronic functions τ_μ^1 and τ_μ^2 are given by

$$\tau_\mu^1 = A(q^2)\gamma_\mu + iB(q^2)\sigma_{\mu\nu}q^\nu + C(q^2)q_\mu - D(q^2)\gamma_\mu\gamma_5 - iE(q^2)\sigma_{\mu\nu}q^\nu\gamma^5 - F(q^2)q_\mu\gamma^5 \quad (12)$$

$$\tau_\mu^2 = G(q^2)\gamma_\mu + iH(q^2)\sigma_{\mu\nu}q^\nu + I(q^2)q_\mu - J(q^2)\gamma_\mu\gamma_5 - iK(q^2)\sigma_{\mu\nu}q^\nu\gamma^5 - L(q^2)q_\mu\gamma^5 \quad (13)$$

The auxiliary functions from $A(q^2)$ to $L(q^2)$ given in Eqs.(12) and (13) contains both short and long distance effects which are encapsulated in terms of Wilson coefficients and form factors. The explicit form of these functions can be

written as follows

$$\begin{aligned}
A(q^2) &= C_9^{tot} f_1(q^2) - \frac{2m_b}{q^2} C_7^{eff} f_1^T(q^2) \\
B(q^2) &= C_9^{tot} f_2(q^2) - \frac{2m_b}{q^2} C_7^{eff} f_2^T(q^2) \\
C(q^2) &= C_9^{tot} f_3(q^2) - \frac{2m_b}{q^2} C_7^{eff} f_3^T(q^2) \\
D(q^2) &= C_9^{tot} g_1(q^2) - \frac{2m_b}{q^2} C_7^{eff} g_1^T(q^2) \\
E(q^2) &= C_9^{tot} g_2(q^2) - \frac{2m_b}{q^2} C_7^{eff} g_2^T(q^2) \\
F(q^2) &= C_9^{tot} g_3(q^2) - \frac{2m_b}{q^2} C_7^{eff} g_3^T(q^2) \\
G(q^2) &= C_{10}^{tot} f_1(q^2) \\
H(q^2) &= C_{10}^{tot} f_2(q^2) \\
I(q^2) &= C_{10}^{tot} f_3(q^2) \\
J(q^2) &= C_{10}^{tot} g_1(q^2) \\
K(q^2) &= C_{10}^{tot} g_2(q^2) \\
L(q^2) &= C_{10}^{tot} g_3(q^2)
\end{aligned} \tag{14}$$

The matrix element for the decay $\Lambda_b \rightarrow \Lambda \ell^+ \ell^-$ given in Eq. (11) is useful to calculate the physical observables. The formula for double differential decay rate can be written as

$$\frac{d^2\Gamma(\Lambda_b \rightarrow \Lambda \ell^+ \ell^-)}{d\cos\theta ds} = \frac{1}{2M_{\Lambda}^3} \frac{2\beta\sqrt{\lambda}}{(8\pi)^3} |\mathcal{M}^{tot}|^2 \tag{15}$$

where $\beta \equiv \sqrt{1 - \frac{4m_\ell^2}{s}}$ and $\lambda = \lambda(M_{\Lambda_b}, M_{\Lambda}, s) \equiv M_{\Lambda_b}^4 + M_{\Lambda}^4 + s^2 - 2M_{\Lambda_b}^2 M_{\Lambda}^2 - 2sM_{\Lambda_b}^2 - 2sM_{\Lambda}^2$. Also s is the square of the momentum transfer q and θ is the angle between lepton and final state baryon in the rest frame of Λ_b . By using the expression of amplitude given in Eq.(11) and integration over $\cos\theta$, one can get the expression of the dilepton invariant mass spectrum as

$$\frac{d\Gamma(\Lambda_b \rightarrow \Lambda \ell^+ \ell^-)}{ds} = \frac{G_F^2 \alpha_{EM}^2 \beta \sqrt{\lambda}}{2^{13} \pi^5 M_{\Lambda_b}^3} |V_{tb} V_{ts}^*|^2 \mathcal{M}_1 \tag{16}$$

with

$$\begin{aligned}
\mathcal{M}_1 &= \left\{ \frac{8}{3} \left((3\Delta_1 + (\frac{4m_\ell^2 \lambda}{s} - \lambda))(|A|^2 + |D|^2) + 12m_\ell^2(\Delta|A|^2 + \omega|D|^2) + 3s(\Delta_1|B|^2 + \Delta_2|E|^2) \right. \right. \\
&\quad + (12m_\ell^2\Delta_3 + \lambda(s - 4m_\ell^2))(|B|^2 + |E|^2) + 3(\Delta_1|G|^2 + \Delta_2|J|^2) - 12m_\ell^2(\Delta|G|^2 - \omega|J|^2) \\
&\quad - 48m_\ell^2 M_{\Lambda_b} M_{\Lambda} (|G|^2 - |J|^2) - (\lambda - \frac{4m_\ell^2 \lambda}{s})(|G|^2 + |J|^2) + (s - 4m_\ell^2)(|H|^2(3\Delta_1 + \lambda) + |K|^2(3\Delta_2 + \lambda))) \\
&\quad + 32m_\ell^2 s(\omega|I|^2 + \Delta|L|^2) - 16\Delta(M_{\Lambda_b} + M_{\Lambda})(s + 2m_\ell^2)(AB^* + BA^*) - 16\omega(s - 4m_\ell^2)(M_{\Lambda_b} - M_{\Lambda})(JK^* + KJ^*) \\
&\quad \left. \left. - 32m_\ell^2 \Delta(M_{\Lambda_b} + M_{\Lambda})(JL^* + LJ^*) + 16\omega(s + 2m_\ell^2)(M_{\Lambda_b} - M_{\Lambda})(DE^* + ED^*) \right\} \right. \tag{17}
\end{aligned}$$

where

$$\begin{aligned}
\Delta &\equiv (M_\Lambda - M_{\Lambda_b})^2 - s \\
\omega &\equiv (M_\Lambda + M_{\Lambda_b})^2 - s \\
\omega_1 &\equiv (M_\Lambda + M_{\Lambda_b})^2 + s \\
\omega_2 &\equiv (M_\Lambda - M_{\Lambda_b})^2 + s \\
\omega_3 &\equiv (M_{\Lambda_b}^2 - M_\Lambda^2 + 6M_{\Lambda_b}M_\Lambda - s) \\
\omega_4 &\equiv (M_{\Lambda_b}^2 - M_\Lambda^2 - 6M_{\Lambda_b}M_\Lambda - s) \\
\Delta_1 &\equiv (M_\Lambda^2 - M_{\Lambda_b}^2)^2 - s(4M_{\Lambda_b}M_\Lambda + s) \\
\Delta_2 &\equiv (M_\Lambda^2 - M_{\Lambda_b}^2)^2 + s(4M_{\Lambda_b}M_\Lambda - s) \\
\Delta_3 &\equiv (M_{\Lambda_b}^2 - M_\Lambda^2)^2 - s(M_{\Lambda_b} - M_\Lambda)^2 \\
\Delta_4 &\equiv (M_{\Lambda_b}^2 - M_\Lambda^2)^2 + s(M_{\Lambda_b} - M_\Lambda)^2
\end{aligned}$$

Following the recipe given in ref. [7], one can define the CP -violation asymmetry for the decay $\Lambda_b \rightarrow \Lambda \ell^+ \ell^-$ for both the cases, i.e. with polarized and unpolarized leptons as

$$\mathcal{A}_{CP}(\mathbf{S}^\pm = \mathbf{e}_i^\pm) = \frac{\frac{d\Gamma(\mathbf{S}^-)}{ds} - \frac{d\bar{\Gamma}(\mathbf{S}^+)}{ds}}{\frac{d\Gamma(\mathbf{S}^-)}{ds} + \frac{d\bar{\Gamma}(\mathbf{S}^+)}{ds}} \quad (18)$$

where

$$\begin{aligned}
\frac{d\Gamma(S^-)}{ds} &= \frac{d\Gamma(\Lambda_b \rightarrow \Lambda \ell^+ \ell^- (S^-))}{ds} \\
\frac{d\bar{\Gamma}(S^+)}{ds} &= \frac{d\bar{\Gamma}(\Lambda_b \rightarrow \Lambda \ell^+ \ell^- (S^+))}{ds}.
\end{aligned}$$

The analogous expression for CP conjugated differential decay width is given in ref. [7]. The expression for CP violation asymmetry can be obtained by using Eq. (16) and Eq. (17), so one gets

$$\mathcal{A}_{CP}(\mathbf{S}^\pm = \mathbf{e}_i^\pm) = \frac{1}{2} \left[\frac{\mathcal{M}_1 - \bar{\mathcal{M}}_1}{\mathcal{M}_1 + \bar{\mathcal{M}}_1} \pm \frac{\mathcal{M}_1^i - \bar{\mathcal{M}}_1^i}{\mathcal{M}_1^i + \bar{\mathcal{M}}_1^i} \right] \quad (19)$$

where i represents the longitudinal (L), normal (N) and transverse (T) polarization of the final state leptons.

Also one can write the polarized and unpolarized CP asymmetry as

$$\mathcal{A}_{CP}(s) = \frac{\mathcal{M}_1 - \bar{\mathcal{M}}_1}{\mathcal{M}_1 + \bar{\mathcal{M}}_1}, \quad \mathcal{A}_{CP}^i(s) = \frac{\mathcal{M}_1^i - \bar{\mathcal{M}}_1^i}{\mathcal{M}_1^i + \bar{\mathcal{M}}_1^i} \quad (20)$$

The normalized CP violation asymmetry can be defined by using the above definition as follows

$$\mathcal{A}_{CP}(\mathbf{S}^\pm = e_i^\pm) = \frac{1}{2} [\mathcal{A}_{CP}(s) \pm \mathcal{A}_{CP}^i(s)] \quad (21)$$

In Eq.(21) the positive sign in the second term represents to L and N polarizations, and the negative sign is for T polarization.

The following are the results of unpolarized \mathcal{A}_{CP} and \mathcal{A}_{CP}^i [7]

$$\mathcal{A}_{CP}(s) = \frac{-2\text{Im}(\Lambda_{sb})\mathcal{Q}(s)}{\mathcal{M}_1 + 2\text{Im}(\Lambda_{sb})\mathcal{Q}(s)} \quad (22)$$

$$\mathcal{A}_{CP}^i(s) = \frac{-2\text{Im}(\Lambda_{sb})\mathcal{Q}^i(s)}{\mathcal{M}_1 + 2\text{Im}(\Lambda_{sb})\mathcal{Q}^i(s)} \quad (23)$$

The explicit form of $\mathcal{Q}(s)$ and the $\mathcal{Q}^i(s)$ are given below.

$$\mathcal{Q}(s) = \frac{16}{3s} \{ \mathcal{H}_1 \text{Im}(C_7 C_9^{Z^{*'}}) - \mathcal{H}_2 \text{Im}(C_9 C_9^{Z^{*'}}) + \mathcal{H}_3 \text{Im}(C_{10} C_{10}^{Z^{*'}}) \} \quad (24)$$

The explicit form of the functions $\mathcal{H}_1, \mathcal{H}_2$ and \mathcal{H}_3 can be written as

$$\begin{aligned} \mathcal{H}_1 = & \{ \lambda s(s - 4m_\ell^2)(\mathcal{D}_4\mathcal{D}_3^* - \mathcal{D}_{10}\mathcal{D}_9^*) - 6s\Delta(M_{\Lambda_b} + M_\Lambda)(s + 2m_\ell^2)(\mathcal{D}_4\mathcal{D}_1^* + \mathcal{D}_2\mathcal{D}_3^*) \\ & + 6s\omega(M_{\Lambda_b} - M_\Lambda)(s + 2m_\ell^2)(\mathcal{D}_{10}\mathcal{D}_7^* - \mathcal{D}_8\mathcal{D}_9^*) \\ & + 3s(s + 4m_\ell^2)((\Delta_1 + \Delta_3)\mathcal{D}_4\mathcal{D}_3^* - (\Delta_2 + \Delta_4)\mathcal{D}_{10}\mathcal{D}_9^*) \\ & + 3s(\Delta(\omega_1 + 4m_\ell^2)\mathcal{D}_2\mathcal{D}_1^* + \omega(\omega_2 + 4m_\ell^2)\mathcal{D}_8\mathcal{D}_7^*) - \lambda(s - 4m_\ell^2)(\mathcal{D}_2\mathcal{D}_1^* + \mathcal{D}_8\mathcal{D}_7^*) \} \end{aligned} \quad (25)$$

$$\begin{aligned} \mathcal{H}_2 = & \{ 3s(\Delta(\omega_1 + 4m_\ell^2)|\mathcal{D}_1|^2 + \omega(\omega_2 + 4m_\ell^2)|\mathcal{D}_7|^2) + \lambda s(s - 4m_\ell^2)(|\mathcal{D}_3|^2 + |\mathcal{D}_9|^2) \\ & - 6s\Delta(M_{\Lambda_b} + M_\Lambda)(s + 2m_\ell^2)(\mathcal{D}_1\mathcal{D}_3^* + \mathcal{D}_3\mathcal{D}_1^*) + 3s(s + 4m_\ell^2)(\Delta_1|\mathcal{D}_3|^2 + \Delta_4|\mathcal{D}_9|^2) \\ & - 6s\omega(M_{\Lambda_b} - M_\Lambda)(s + 2m_\ell^2)(\mathcal{D}_7\mathcal{D}_9^* + \mathcal{D}_9\mathcal{D}_7^*) \} \end{aligned} \quad (26)$$

$$\begin{aligned} \mathcal{H}_3 = & \{ \lambda s(s - 4m_\ell^2)(|\mathcal{D}_1|^2 + |\mathcal{D}_7|^2) + 3s(\lambda_1|\mathcal{D}_1|^2 + \lambda_2|\mathcal{D}_7|^2) + 6s\Delta(M_{\Lambda_b} + M_\Lambda)(s - 4m_\ell^2)(\mathcal{D}_1\mathcal{D}_3^* + \mathcal{D}_3\mathcal{D}_1^*) \\ & + 12sm_\ell^2\Delta(M_{\Lambda_b} + M_\Lambda)(\mathcal{D}_7\mathcal{D}_{11}^* + \mathcal{D}_{11}\mathcal{D}_7^*) - 3s(s - 4m_\ell^2)(\Delta_1|\mathcal{D}_3|^2 + \Delta_2|\mathcal{D}_9|^2) - 12s^2m_\ell^2(\omega|\mathcal{D}_5|^2 + \Delta|\mathcal{D}_{11}|^2) \\ & - \lambda s(s - 4m_\ell^2)(|\mathcal{D}_3|^2 + |\mathcal{D}_9|^2) - 6s\omega(M_{\Lambda_b} - M_\Lambda)(s - 4m_\ell^2)(\mathcal{D}_9\mathcal{D}_7^* + \mathcal{D}_7\mathcal{D}_9^*) \\ & + 2s\omega m_\ell^2(M_{\Lambda_b} - M_\Lambda)\mathcal{D}_1\mathcal{D}_5^* \} \end{aligned} \quad (27)$$

The expressions for polarized CP asymmetry are given below.

A. Longitudinal CP violation

The longitudinal lepton polarization can be written as

$$\mathcal{A}_{CP}^L(s) = \frac{-2\text{Im}(\Lambda_{sb})\mathcal{Q}^L(s)}{\mathcal{M}_1 + 2\text{Im}(\Lambda_{sb})\mathcal{Q}^L(s)} \quad (28)$$

with

$$\begin{aligned} \mathcal{Q}^L = & \frac{8}{3} \left\{ \frac{1}{s} (\mathcal{H}_1^L \text{Im}(C_7 C_9^{Z''}) - \mathcal{H}_2^L \text{Im}(C_9 C_9^{Z''}) + \mathcal{H}_3^L \text{Im}(C_{10} C_{10}^{Z''})) + \frac{1}{\sqrt{s}} (\mathcal{H}_4^L \text{Im}(C_7 C_{10}^{Z''}) \right. \\ & \left. - \mathcal{H}_5^L \text{Im}(C_9 C_{10}^{Z''})) \right\} \end{aligned} \quad (29)$$

where $\mathcal{H}_1^L = \mathcal{H}_1, \mathcal{H}_2^L = \mathcal{H}_2$ and $\mathcal{H}_3^L = \mathcal{H}_3$. Also \mathcal{M}_1 is defined in Eq. (17) and the terms \mathcal{H}_4^L and \mathcal{H}_5^L are given as follows

$$\begin{aligned} \mathcal{H}_4^L = & \sqrt{s - 4m_\ell^2} \{ 3s(\Delta_1(\mathcal{D}_4\mathcal{D}_3^*) - \Delta_2(\mathcal{D}_{10}\mathcal{D}_9^*)) + \lambda s(\mathcal{D}_4\mathcal{D}_3^* - \mathcal{D}_{10}\mathcal{D}_9^*) \\ & - 6s\Delta(M_{\Lambda_b} + M_\Lambda)(\mathcal{D}_2\mathcal{D}_3^* + \mathcal{D}_4\mathcal{D}_1^*) - 6s\omega(M_{\Lambda_b} - M_\Lambda)(\mathcal{D}_8\mathcal{D}_9^* + \mathcal{D}_{10}\mathcal{D}_7^*) + (3\Delta_2 - \lambda)(\mathcal{D}_2\mathcal{D}_1^* + \mathcal{D}_8\mathcal{D}_7^*) \} \end{aligned} \quad (30)$$

$$\begin{aligned} \mathcal{H}_5^L = & \sqrt{s - 4m_\ell^2} \{ ((3\Delta_1 - \lambda)|\mathcal{D}_1|^2 - (3\Delta_2 + \lambda)|\mathcal{D}_7|^2 - 6s\Delta(M_{\Lambda_b} + M_\Lambda)(\mathcal{D}_1\mathcal{D}_3^* + \mathcal{D}_3\mathcal{D}_1^*) \\ & + 6s\omega(M_{\Lambda_b} - M_\Lambda)(\mathcal{D}_7\mathcal{D}_9^* + \mathcal{D}_9\mathcal{D}_7^*) + s((3\Delta_1 + \lambda)|\mathcal{D}_3|^2 + (3\Delta_2 + \lambda)|\mathcal{D}_9|^2) \} \end{aligned} \quad (31)$$

B. Normal CP violation Asymmetry

In case of the normally polarized lepton, the corresponding normal CP violation can be expressed as

$$\mathcal{A}_{CP}^N(s) = \frac{-2\text{Im}(\Lambda_{sb})\mathcal{Q}^N(s)}{\mathcal{M}_1 + 2\text{Im}(\Lambda_{sb})\mathcal{Q}^N(s)} \quad (32)$$

where

$$\begin{aligned} \mathcal{Q}^N = & \left\{ \frac{8}{3s} (\mathcal{H}_1^N \text{Im}(C_7 C_9^{Z''}) - \mathcal{H}_2^N \text{Im}(C_9 C_9^{Z''}) + \mathcal{H}_3^N \text{Im}(C_{10} C_{10}^{Z''})) + \frac{4\pi\sqrt{\lambda}}{\sqrt{s}} (\mathcal{H}_4^N \text{Im}(C_9 C_{10}^{Z''}) \right. \\ & \left. + \mathcal{H}_5^N \text{Im}(C_{10} C_9^{Z''}) - \mathcal{H}_6^N \text{Im}(C_7 C_{10}^{Z''})) \right\} \end{aligned} \quad (33)$$

and

$$\begin{aligned}
\mathcal{H}_1^N = & 3\pi\sqrt{\lambda}m_\ell s^{3/2}((M_{\Lambda_b} - M_\Lambda)(\mathcal{D}_{10}\mathcal{D}_1^* - \mathcal{D}_2\mathcal{D}_9^*) - (\mathcal{D}_8\mathcal{D}_1^* - \mathcal{D}_2\mathcal{D}_7^*)) \\
& + 3\pi\sqrt{\lambda}m_\ell s^{3/2}((M_{\Lambda_b}^2 - M_\Lambda^2)(\mathcal{D}_4\mathcal{D}_9^* - \mathcal{D}_{10}\mathcal{D}_3^*) + (M_{\Lambda_b} + M_\Lambda)(\mathcal{D}_4\mathcal{D}_7^* + \mathcal{D}_8\mathcal{D}_3^*)) \\
& + 6s\Delta(s + 2m_\ell^2)(M_{\Lambda_b} + M_\Lambda)(\mathcal{D}_2\mathcal{D}_3^* - \mathcal{D}_4\mathcal{D}_1^*) + \lambda s(s - 4m_\ell^2)(\mathcal{D}_4\mathcal{D}_3^* - \mathcal{D}_{10}\mathcal{D}_9^* - \mathcal{D}_2\mathcal{D}_1^*) \\
& + 3s(s + 4m_\ell^2)((\Delta_1 + \Delta_3)\mathcal{D}_4\mathcal{D}_3^* - (\Delta_2 + \Delta_4)\mathcal{D}_{10}\mathcal{D}_9^*) - \lambda(s - 4m_\ell^2)\mathcal{D}_8\mathcal{D}_7^* \\
& + 6\omega s(s + 2m_\ell^2)(M_{\Lambda_b} - M_\Lambda)(\mathcal{D}_8\mathcal{D}_9^* - \mathcal{D}_{10}\mathcal{D}_7^*) + 3s(\Delta(\omega_1 + 4m_\ell^2)\mathcal{D}_2\mathcal{D}_1^* + \omega(\omega_2 + 4m_\ell^2)\mathcal{D}_8\mathcal{D}_7^*) \quad (34)
\end{aligned}$$

$$\begin{aligned}
\mathcal{H}_2^N = & \{3\pi\sqrt{\lambda}m_\ell s^{3/2}((M_{\Lambda_b} + M_\Lambda)(\mathcal{D}_7\mathcal{D}_3^* + \mathcal{D}_3\mathcal{D}_7^*) - (M_{\Lambda_b} - M_\Lambda)(\mathcal{D}_1\mathcal{D}_9^* - \mathcal{D}_9\mathcal{D}_1^*)) \\
& - 3\pi\sqrt{\lambda}m_\ell s^{3/2}(\mathcal{D}_1\mathcal{D}_7^* + \mathcal{D}_7\mathcal{D}_1^*) - 6s\Delta(s + 2m_\ell^2)(M_{\Lambda_b} + M_\Lambda)(\mathcal{D}_1\mathcal{D}_3^* + \mathcal{D}_3\mathcal{D}_1^*) \\
& - \lambda(s - 4m_\ell^2)(|\mathcal{D}_1|^2 + |\mathcal{D}_7|^2) + 6\omega s(s + 2m_\ell^2)(M_{\Lambda_b} - M_\Lambda)(\mathcal{D}_7\mathcal{D}_9^* + \mathcal{D}_9\mathcal{D}_7^*) \\
& + 3s(\Delta(\omega_1 + 4m_\ell^2)|\mathcal{D}_1|^2 + \omega(\omega_2 + 4m_\ell^2)|\mathcal{D}_7|^2) + 3s(s + 4m_\ell^2)((\Delta_1 + \Delta_3)|\mathcal{D}_3|^2 \\
& + (\Delta_2 + \Delta_4)|\mathcal{D}_9|^2 + \lambda s(s - 4m_\ell^2)(|\mathcal{D}_3|^2 + |\mathcal{D}_9|^2) + 3\pi\sqrt{\lambda}m_\ell s^{3/2}(M_{\Lambda_b}^2 - M_\Lambda^2)\mathcal{D}_3\mathcal{D}_9^*) \quad (35)
\end{aligned}$$

$$\begin{aligned}
\mathcal{H}_4^N = & m_\ell\{s^2(\mathcal{D}_3\mathcal{D}_5^* + \mathcal{D}_9\mathcal{D}_{11}^*) - (M_{\Lambda_b}^2 - M_\Lambda^2)(|\mathcal{D}_1|^2 + |\mathcal{D}_7|^2) - s(\mathcal{D}_1\mathcal{D}_5^* + \mathcal{D}_7\mathcal{D}_{11}^*) \\
& + s((M_{\Lambda_b} - M_\Lambda)\mathcal{D}_3\mathcal{D}_1^* - (M_{\Lambda_b} + M_\Lambda)\mathcal{D}_9\mathcal{D}_7^*)\} \quad (36)
\end{aligned}$$

$$\begin{aligned}
\mathcal{H}_5^N = & m_\ell\{s(M_{\Lambda_b} + M_\Lambda)(\mathcal{D}_5\mathcal{D}_1^* + \mathcal{D}_7\mathcal{D}_9^*) + s(M_{\Lambda_b} - M_\Lambda)(\mathcal{D}_{11}\mathcal{D}_7^* + \mathcal{D}_5\mathcal{D}_1^*) - (M_{\Lambda_b}^2 - M_\Lambda^2)(|\mathcal{D}_1|^2 + |\mathcal{D}_7|^2) \\
& + s^2(\mathcal{D}_{11}\mathcal{D}_9^* + \mathcal{D}_5\mathcal{D}_3^*)\} \quad (37)
\end{aligned}$$

$$\begin{aligned}
\mathcal{H}_6^N = & m_\ell\{s(M_{\Lambda_b} - M_\Lambda)(\mathcal{D}_8\mathcal{D}_{11}^* - \mathcal{D}_4\mathcal{D}_1^*) + s^2(\mathcal{D}_4\mathcal{D}_5^* - \mathcal{D}_{10}\mathcal{D}_{11}^*) + s(M_{\Lambda_b} + M_\Lambda)(\mathcal{D}_{10}\mathcal{D}_7^* - \mathcal{D}_2\mathcal{D}_5^*) \\
& - (M_{\Lambda_b}^2 - M_\Lambda^2)(\mathcal{D}_2\mathcal{D}_1^* + \mathcal{D}_8\mathcal{D}_7^*)\} \quad (38)
\end{aligned}$$

C. Transverse CP -Asymmetry

The transverse CP violation asymmetry can be written as

$$\mathcal{A}_{CP}^T(s) = \frac{-2\text{Im}(\Lambda_{sb})\mathcal{Q}^T(s)}{\mathcal{M}_1 + 2\text{Im}(\Lambda_{sb})\mathcal{Q}^T(s)} \quad (39)$$

with

$$\begin{aligned}
\mathcal{Q}^T(s) = & \left\{ \frac{8}{3s}(\mathcal{H}_1^T \text{Im}(C_7 C_9^{Z*'}) - \mathcal{H}_2^T \text{Im}(C_9 C_9^{Z*'})) + 4\pi\sqrt{\lambda(s - 4m_\ell^2)}(\mathcal{H}_3^T \text{Re}(C_9 C_{10}^{Z*'})) \right. \\
& \left. + \mathcal{H}_4^T \text{Re}(C_{10} C_9^{Z*'}) - \mathcal{H}_5^T \text{Re}(C_7 C_{10}^{Z*'}) + \frac{4}{3s}(\mathcal{H}_6^{T^A} \text{Im}(C_{10} C_{10}^{Z*'}) + \mathcal{H}_6^{T^B} \text{Re}(C_{10} C_{10}^{Z*'})) \right\} \quad (40)
\end{aligned}$$

where $\mathcal{H}_1^T = \mathcal{H}_1^L, \mathcal{H}_2^T = \mathcal{H}_3^L, \mathcal{H}_6^{T^A} = (\mathcal{H}_6^{T^1} + \mathcal{H}_6^{T^2} + \mathcal{H}_6^{T^3})$ and $\mathcal{H}_6^{T^B} = (\mathcal{H}_6^{T^4} + \mathcal{H}_6^{T^5})$. The different terms given in above equation can be expressed as

$$\mathcal{H}_3^T = m_\ell \{ (M_{\Lambda_b} + M_\Lambda) (\mathcal{D}_3 \mathcal{D}_7^* + \mathcal{D}_7 \mathcal{D}_3^*) + (M_{\Lambda_b}^2 - M_\Lambda^2) (\mathcal{D}_3 \mathcal{D}_9^* + \mathcal{D}_9 \mathcal{D}_3^*) + s (\mathcal{D}_3 \mathcal{D}_9^* - \mathcal{D}_9 \mathcal{D}_3^*) \} \quad (41)$$

$$\mathcal{H}_4^T = m_\ell \{ (M_{\Lambda_b} - M_\Lambda) (\mathcal{D}_1 \mathcal{D}_9^* + \mathcal{D}_9 \mathcal{D}_1^*) - (M_{\Lambda_b}^2 - M_\Lambda^2) (\mathcal{D}_3 \mathcal{D}_9^* - \mathcal{D}_9 \mathcal{D}_3^*) + s (\mathcal{D}_3 \mathcal{D}_9^* - \mathcal{D}_9 \mathcal{D}_3^*) - (M_{\Lambda_b} + M_\Lambda) (\mathcal{D}_3 \mathcal{D}_7^* + \mathcal{D}_7 \mathcal{D}_3^*) \} \quad (42)$$

$$\mathcal{H}_5^T = m_\ell \{ (M_{\Lambda_b} + M_\Lambda) (\mathcal{D}_4 \mathcal{D}_7^* + \mathcal{D}_8 \mathcal{D}_3^*) + (M_{\Lambda_b}^2 - M_\Lambda^2 + s) (\mathcal{D}_4 \mathcal{D}_9^* - \mathcal{D}_{10} \mathcal{D}_3^*) + (M_{\Lambda_b} - M_\Lambda) (\mathcal{D}_{10} \mathcal{D}_1^* - \mathcal{D}_2 \mathcal{D}_1^*) \} \quad (43)$$

$$\begin{aligned} \mathcal{H}_6^{T^1} = & \{ (6s^4 - 24s^3 m_\ell^2 - 24s^2 M_{\Lambda_b} M_\Lambda + 2s^2 \Delta_5) (|\mathcal{D}_3|^2 + |\mathcal{D}_9|^2) + 24s^3 m_\ell^2 (|\mathcal{D}_5|^2 + |\mathcal{D}_{11}|^2) \\ & + 12s^3 ((M_{\Lambda_b} - M_\Lambda) \mathcal{D}_9 \mathcal{D}_7^* - (M_{\Lambda_b} + M_\Lambda) \mathcal{D}_3 \mathcal{D}_1^*) + 48m_\ell^2 M_{\Lambda_b} M_\Lambda (|\mathcal{D}_3|^2 - |\mathcal{D}_9|^2) \\ & + 12m_\ell^2 ((M_{\Lambda_b} + M_\Lambda) (2\mathcal{D}_3 \mathcal{D}_1^* + \mathcal{D}_{11} \mathcal{D}_7^*) + (M_{\Lambda_b} - M_\Lambda) (2\mathcal{D}_9 \mathcal{D}_7^* - \mathcal{D}_5 \mathcal{D}_1^*)) \\ & + 12m_\ell^2 (M_{\Lambda_b} (M_{\Lambda_b} + M_\Lambda) |\mathcal{D}_5|^2 - (M_{\Lambda_b} - M_\Lambda)^2 |\mathcal{D}_{11}|^2) \\ & + 6(M_{\Lambda_b}^2 - M_\Lambda^2) ((M_{\Lambda_b} + M_\Lambda) \mathcal{D}_9 \mathcal{D}_7^* - (M_{\Lambda_b} - M_\Lambda) \mathcal{D}_3 \mathcal{D}_1^*) \} \end{aligned} \quad (44)$$

$$\mathcal{H}_6^{T^2} = 8m_\ell^2 s \{ 3(M_{\Lambda_b}^2 - M_\Lambda^2) ((M_{\Lambda_b}^2 - M_\Lambda^2) (|\mathcal{D}_3|^2 + |\mathcal{D}_9|^2) + (M_{\Lambda_b} + M_\Lambda) (\mathcal{D}_5 \mathcal{D}_1^* - 2\mathcal{D}_9 \mathcal{D}_7^*) + (M_{\Lambda_b} - M_\Lambda) (2\mathcal{D}_3 \mathcal{D}_1^* - \mathcal{D}_{11} \mathcal{D}_7^*)) + \lambda (|\mathcal{D}_3|^2 + |\mathcal{D}_9|^2) \} \quad (45)$$

$$\begin{aligned} \mathcal{H}_6^{T^3} = & \{ (2s\lambda - 8m_\ell^2 \lambda) (|\mathcal{D}_1|^2 + |\mathcal{D}_7|^2) + (24sm_\ell^2 - 6s) (\Delta_1 |\mathcal{D}_1|^2 - \Delta_2 |\mathcal{D}_7|^2) \\ & + 24sm_\ell^2 (\omega_4 |\mathcal{D}_1|^2 + \omega_3 |\mathcal{D}_7|^2) + 12s (s - 4m_\ell^2) (\Delta (M_{\Lambda_b} + M_\Lambda) \mathcal{D}_1 \mathcal{D}_3^* - \omega (M_{\Lambda_b} - M_\Lambda) \mathcal{D}_7 \mathcal{D}_9^*) \\ & + 24sm_\ell^2 (\Delta (M_{\Lambda_b} + M_\Lambda) \mathcal{D}_7 \mathcal{D}_{11}^* + \omega (M_{\Lambda_b} - M_\Lambda) \mathcal{D}_1 \mathcal{D}_5^*) \} \end{aligned} \quad (46)$$

$$\mathcal{H}_6^{T^4} = 3m_\ell \pi s^2 \sqrt{\lambda(s - 4m_\ell^2)} \{ (|\mathcal{D}_3|^2 + |\mathcal{D}_9|^2) - (\mathcal{D}_3 \mathcal{D}_5^* + \mathcal{D}_5 \mathcal{D}_3^*) + (\mathcal{D}_9 \mathcal{D}_{11}^* - \mathcal{D}_{11} \mathcal{D}_9^*) \} \quad (47)$$

$$\begin{aligned} \mathcal{H}_6^{T^5} = & 3m_\ell \pi s \sqrt{\lambda(s - 4m_\ell^2)} \{ (M_{\Lambda_b} + M_\Lambda) (\mathcal{D}_3 \mathcal{D}_1^* + \mathcal{D}_1 \mathcal{D}_5^* - \mathcal{D}_9 \mathcal{D}_7^*) + (M_{\Lambda_b} - M_\Lambda) (\mathcal{D}_7 \mathcal{D}_{11}^* - \mathcal{D}_{11} \mathcal{D}_7^*) \\ & - (M_{\Lambda_b}^2 - M_\Lambda^2) (|\mathcal{D}_3|^2 + |\mathcal{D}_9|^2) - (|\mathcal{D}_1|^2 + |\mathcal{D}_7|^2) \} \end{aligned} \quad (48)$$

where $\mathcal{D}_{1,3,5} = f_{1,2,3}, \mathcal{D}_{2,4,6} = \frac{2m_b}{s} f_{1,2,3}^T$ and $\mathcal{D}_{7,9,11} = g_{1,2,3}, \mathcal{D}_{8,10,12} = \frac{2m_b}{s} g_{1,2,3}^T$

III. NUMERICAL ANALYSIS

In this section we will discuss the numerical analysis of the unpolarized and polarized CP violation asymmetries for $\Lambda_b \rightarrow \Lambda \ell^+ \ell^-$ with $\ell = \mu, \tau$ decays. In order to see the imprints of the family non-universal Z' gauge boson on the said physical observables, first we have to summarize the numerical values of various input parameters used in calculations such as masses of particles, life time, quark coupling CKM matrix etc., in Table I, while the values of Wilson coefficients are presented in Table-II. The most important input parameters which are important in any hadronic decays are the non perturbative quantities, called form factors, and for the said decay we rely on light cone QCD sum rules approach [47]. The parametrization of the form factors $f_{1,2,3}$, $g_{1,2,3}$, $f_{2,3}^T$ and $g_{2,3}^T$ are given by

$$f_i(q^2)[g_i(q^2)] = \frac{a}{1 - q^2/m_{fit}^2} + \frac{b}{(1 - q^2/m_{fit}^2)^2}, \quad (49)$$

while the form factors f_1^T and g_1^T are of the form

$$f_1^T[g_1^T] = \frac{c}{1 - q^2/m_{fit}^2} + \frac{c}{(1 - q^2/m_{fit}^2)^2}. \quad (50)$$

The numerical values of the light cone QCD sum rules form factors along with the different fitting parameters [47] are summarized in Table III and IV.

Regarding to the couplings of family non universal Z' -model there are some strong constraint from both inclusive and exclusive B meson decays [23]. The numerical values of quarks and leptons couplings parameters of Z' model are given in Table V, where $\mathcal{S}1$ and $\mathcal{S}2$ represents the two different fitting values for $B_s - \bar{B}_s$ mixing data by the UTfit collaboration [25] and the numerical values of $\mathcal{S}3$ are chosen from [48, 49] and are also summarized in Table V.

It has been already mentioned that $\mathcal{B}_{sb} = |\mathcal{B}_{sb}| e^{-i\phi_{sb}}$ is the off diagonal left handed coupling of Z' boson with quarks and ϕ_{sb} corresponds to a new weak phase, whereas S_{LL} and D_{LL} represent the combination of left and right handed couplings of Z' with the leptons [c.f. Eq. (6)]. In order to fully scan the three scenarios, let us make a

TABLE I: Default values of input parameters used in the calculations.

$M_{\Lambda_b} = 5.620 \text{ GeV}, m_b = 4.28 \text{ GeV}, m_s = 0.13 \text{ GeV},$
$m_\mu = 0.105 \text{ GeV}, m_\tau = 1.77 \text{ GeV},$
$ V_{tb}V_{ts}^* = 45 \times 10^{-3}, \alpha^{-1} = 137, G_F = 1.17 \times 10^{-5} \text{ GeV}^{-2},$
$\tau_{\Lambda_b} = 1.383 \times 10^{-12} \text{ sec}, M_\Lambda = 1.115 \text{ GeV}.$

TABLE II: The Wilson coefficients C_i^μ at the scale $\mu \sim m_b$ in the SM [4].

C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_9	C_{10}
1.107	-0.248	-0.011	-0.026	-0.007	-0.031	-0.313	4.344	-4.669

remark that with $D_{LL} \neq 0$ depict the situation when the new physics comes only from the modification in the Wilson coefficient C_{10} , while, the opposite case, $S_{LL} \neq 0$, indicates that the new physics is due to the change in the Wilson coefficient C_9 [see Eq. (6)]. In Figs. 1 to 8 the average CP violating asymmetries, after integration on s , as a function of S_{LL} and D_{LL} are depicted. The different color codes along with the values of Z' parameters in scenario $\mathcal{S}1$ and $\mathcal{S}2$ are summarize in Table VI. However for scenario $\mathcal{S}3$ the values of Z' parameters with different color codes are given in Eq. (51).

$$|\mathcal{B}_{sb}| = 3 \times 10^{-3} : \begin{cases} \phi_{sb} = -140^\circ, \text{Magenta Dot} \\ \phi_{sb} = -160^\circ, \text{Pink Dot} \end{cases} ; |\mathcal{B}_{sb}| = 5 \times 10^{-3} : \begin{cases} \phi_{sb} = -140^\circ, \text{Green Dot} \\ \phi_{sb} = -160^\circ, \text{Red Dot} \end{cases} \quad (51)$$

Unpolarized CP violation asymmetry:

- Figs.1 and 2 represents the unpolarized CP violation asymmetries for the decay $\Lambda_b \rightarrow \Lambda \mu^+ \mu^- (\tau^+ \tau^-)$ as a function of D_{LL} and S_{LL} respectively. In standard model CP violation asymmetry is zero hence the non-zero value will give us a clue of physics beyond the standard model which is commonly known as New Physics (NP). It is evident from Eq.(22) that the \mathcal{A}_{CP} is proportional to Z' parameters which comes through the imaginary part of the Wilson coefficients as well as of weak phase ϕ_{sb} which conceals in Λ_{sb} (c.f.Eq.(5)). Therefore the dependence on new weak phase ϕ_{sb} is expected and is evident from Figs.1 and 2 where band in each case depicts the variation of new phase ϕ_{sb} in respective scenarios. In Fig.(1) \mathcal{A}_{CP} is plotted vs D_{LL} by changing the values of S_{LL} , ϕ_{sb} and \mathcal{B}_{sb} . In case of μ 's as a final state leptons, the value of \mathcal{A}_{CP} is positive in both scenarios $\mathcal{S}1$ and $\mathcal{S}2$ but for positive values of S_{LL} . However, the value of \mathcal{A}_{CP} reaches to -0.05 when $D_{LL} = -1.6 \times 10^{-2}$ and corresponding $S_{LL} = -6.7 \times 10^{-2}$ depicted by red band. Similarly for the case of τ 's as final state leptons, the value of \mathcal{A}_{CP} is positive in both scenarios for positive values of S_{LL} . However, the value of \mathcal{A}_{CP} is around -0.08 for $D_{LL} = -1.6 \times 10^{-2}$ and $S_{LL} = -6.7 \times 10^{-2}$ shown by red bands.
- Fig. 2 presents the behavior of \mathcal{A}_{CP} with S_{LL} by varying the values of D_{LL} , ϕ_{sb} and \mathcal{B}_{sb} in the range given in Table V. It can be immediately noticed that in case of μ 's the value is small compared to the case when τ 's

TABLE III: Fit parameters for $\Lambda_b \rightarrow \Lambda \ell^- \ell^-$ transition form factors in full theory. Here only central value is given [47]

	a	b	m_{fit}^2
f_1	-0.046	0.368	39.10
f_2	0.0046	-0.017	26.37
f_3	0.006	-0.021	22.99
g_1	-0.220	0.538	48.70
g_2	0.005	-0.018	26.93
g_3	0.035	-0.050	24.26
f_2^T	-0.131	0.426	45.70
f_3^T	-0.046	0.102	28.31
g_2^T	-0.369	0.664	59.37
f_2^T	-0.026	-0.075	23.73

TABLE IV: Fit parameters for $\Lambda_b \rightarrow \Lambda \ell^- \ell^-$ transition form factors in full theory for f_1^T and g_1^T Here only central value is given [47]

	c	$m_{fit}'^2$	$m_{fit}''^2$
f_1^T	-1.191	23.81	59.96
g_1^T	-0.653	24.15	48.52

TABLE V: The numerical values of the Z' parameters [23, 25, 48, 49].

	$ \mathcal{B}_{sb} \times 10^{-3}$	$\phi_{sb}(inDegree)$	$S_{LL} \times 10^{-2}$	$D_{LL} \times 10^{-2}$
$\mathcal{S}1$	1.09 ± 0.22	-72 ± 7	-2.8 ± 3.9	-6.7 ± 2.6
$\mathcal{S}2$	2.20 ± 0.15	-82 ± 4	-1.2 ± 1.4	-2.5 ± 0.9
$\mathcal{S}3$	4.0 ± 1.5	150 ± 10 or (-150 ± 10)	0.8	-2.6

are final state leptons. In both cases \mathcal{A}_{CP} is an increasing function of the S_{LL} . In $\Lambda_b \rightarrow \Lambda \tau^+ \tau^-$ the value of unpolarized CP asymmetry is around -0.1 when $S_{LL} = -6.7 \times 10^{-2}$.

The values of unpolarized CP violation asymmetries in scenario $\mathcal{S}3$ for $\Lambda_b \rightarrow \Lambda \mu^+ \mu^-$ and $\Lambda_b \rightarrow \Lambda \tau^+ \tau^-$ are shown by different color dots in Figs. 2(a) and 2(b), respectively. It can be noticed that the value of unpolarized CP violation asymmetry is positive maximum in this scenario when $\phi_{sb} = -140^\circ$, $|\mathcal{B}_{sb}| = 5 \times 10^{-3}$ and it is depicted by the green dot in these figures. Irrespective of the negative or positive values of the new weak phase (ϕ_{sb}) the value of CP asymmetry remains positive for all values of \mathcal{B}_{sb} which is an entirely distinctive feature compared to the first two scenarios where CP asymmetry climb from negative to positive value.

Longitudinal polarized CP violation asymmetry:

- The longitudinal polarized CP violation asymmetry \mathcal{A}_{CP}^L is plotted in Figs. 3 and 4. From Eq. (29) it can be noticed that Q^L is proportional to the imaginary part of the combination of Wilson coefficients which involve C_7 , C_9 and C_{10} both in the SM as well as in the Z' model. Even though, the Wilson coefficient C_7 does not get contribution from the Z' , but the change in the Wilson coefficients C_9 and C_{10} due to the parameters of Z' model will make the \mathcal{A}_{CP}^L sensitive to the change arising due to extra neutral boson Z' . In Fig. 3(a) and 3(b), we have plotted the \mathcal{A}_{CP}^L vs D_{LL} by fixing the values of S_{LL} and other Z' parameters in the range given in Table V. We can see that the value of \mathcal{A}_{CP}^L increases from 0.008 to 0.053 when μ 's are the final state leptons and from 0.004 to 0.030 in case of τ 's as final state leptons which can be visualized from the colour bands that corresponds to scenario $\mathcal{S}1(\mathcal{S}2)$. The situation when the longitudinal polarized CP violation asymmetry is plotted with S_{LL} by taking other parameters in the range given in Table V and it is displayed in Fig.4. Here we can see that it is an increasing function of S_{LL} where in $\mathcal{S}1$ and $\mathcal{S}2$ the value increase from 0.01(0.005) to

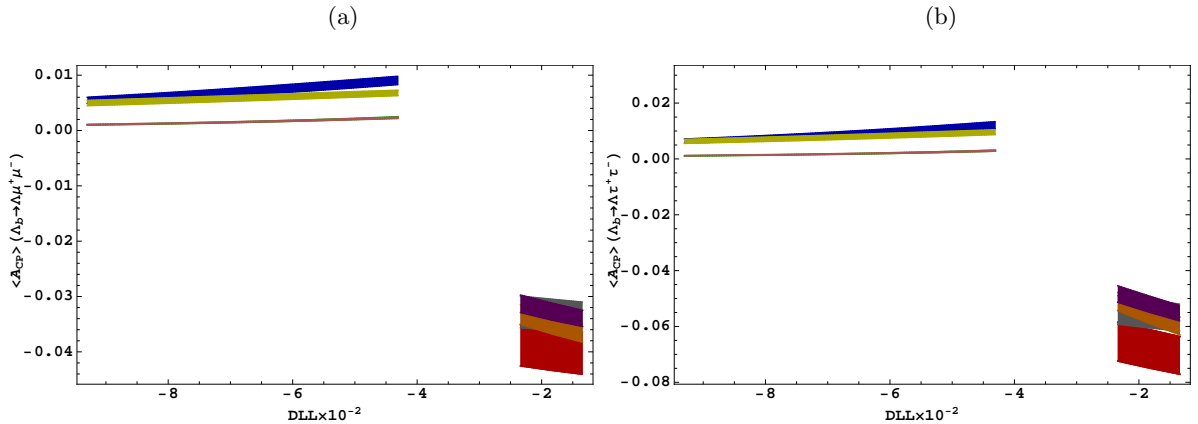


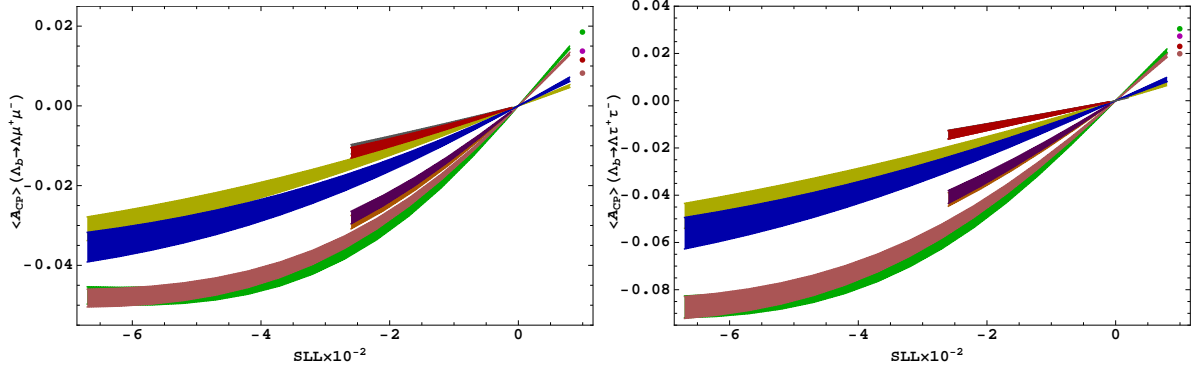
FIG. 1: Unpolarized CP violation asymmetry \mathcal{A}_{CP} as function of D_{LL} for $\Lambda_b \rightarrow \Lambda \mu^+ \mu^- (\tau^+ \tau^-)$ for scenarios $\mathcal{S}1$, $\mathcal{S}2$ and $\mathcal{S}3$. The red, blue, grey and yellow bands corresponds to $\mathcal{S}1$. Green, orange, pink and purple band corresponds to $\mathcal{S}2$. The dots of different colors corresponds to $\mathcal{S}3$. The band in each case depicts the variations of ϕ_{sb} in respective scenario.

TABLE VI: Color bands for the Figs. 1 – 8 $\langle \mathcal{A}_{CP} \rangle$ and $\langle \mathcal{A}_{CP}^i \rangle$ vs S_{LL} and D_{LL} for scenarios $\mathcal{S}1$ and $\mathcal{S}2$.

Color Region	ϕ_{sb}	$ \mathcal{B}_{sb} \times 10^{-3}$	$\langle \mathcal{A}_{CP} \rangle$ and $\langle \mathcal{A}_{CP}^i \rangle$ vs S_{LL} $D_{LL} \times 10^{-2}$	$\langle \mathcal{A}_{CP} \rangle$ and $\langle \mathcal{A}_{CP}^i \rangle$ vs D_{LL} $S_{LL} \times 10^{-2}$
Blue	-79° -65°	+1.31	-4.1	+1.1
Red	-79° -65°	+1.31	-9.3	-6.7
Yellow	-79° -65°	+0.87	-4.1	+1.1
Gray	-79° -65°	+0.87	-9.3	-6.7
Green	-86° -78°	+2.35	-1.6	+0.2
Orange	-86° -78°	+2.35	-3.4	-2.6
Pink	-86° -78°	+2.05	-1.6	+0.2
Purple	-86° -78°	+2.05	-3.4	-2.6

(a)

(b)

FIG. 2: Unpolarized CP violation asymmetry \mathcal{A}_{CP} as function of S_{LL} for $\Lambda_b \rightarrow \Lambda \mu^+ \mu^- (\tau^+ \tau^-)$ for scenarios $\mathcal{S}1$, $\mathcal{S}2$ and $\mathcal{S}3$. The color and band description is same as in Fig. 1.

0.05(0.025) when we have $\mu's(\tau's)$ as final state leptons and it is clearly visible from the red(pink) band. It can also be seen in Fig. 4a, that value of the longitudinal polarized CP violation asymmetry in scenario $\mathcal{S}3$ is much suppressed when we have $\mu's$ as final state leptons. However, in case of the $\tau's$ the value of the longitudinal CP violation asymmetry is around 0.030 when $\phi_{sb} = -140^\circ$ and $|\mathcal{B}_{sb}| = 5 \times 10^{-3}$. It is shown with the green dot in Fig. 4b. It can be noticed that the value of longitudinal polarized CP violation asymmetry in $\Lambda_b \rightarrow \Lambda \tau^+ \tau^-$ is significantly different from its value in the $\mathcal{S}1$ and $\mathcal{S}2$. Hence, by measuring \mathcal{A}_{CP}^L one can not only segregate the NP coming through the Z' boson but can also distinguish the three scenarios.

Normal polarized CP violation asymmetry:

- Contrary to the \mathcal{A}_{CP} and \mathcal{A}_{CP}^L , the normal polarized CP violation asymmetry (\mathcal{A}_{CP}^N) is an order of magnitude smaller in case of $\mu's$ compared to the $\tau's$ as final state leptons. By looking at the Eq. (33). The \mathcal{A}_{CP}^N comes from the function Q^N which contains $\mathcal{H}_1, \dots, \mathcal{H}_6$. In Eqs. (34 - 38) it is clear that these asymmetries are proportional to the lepton mass and their suppression in case of muon is obvious and Figs. 5(a) and 6(a) depict this fact. Coming to the Figs. 5(b) and 6(b) we can see that the \mathcal{A}_{CP}^N is very sensitive to the parameters of Z' both in the $\mathcal{S}1$ and $\mathcal{S}2$. In Fig. 5(b), the value of \mathcal{A}_{CP}^N decreases from 0.040 to 0.018 in the parameter range of Z' in $\mathcal{S}1$ and from 0.048 to 0.028 in $\mathcal{S}2$. The situation remains the same as in Fig. 5 when \mathcal{A}_{CP}^N is plotted with S_{LL}

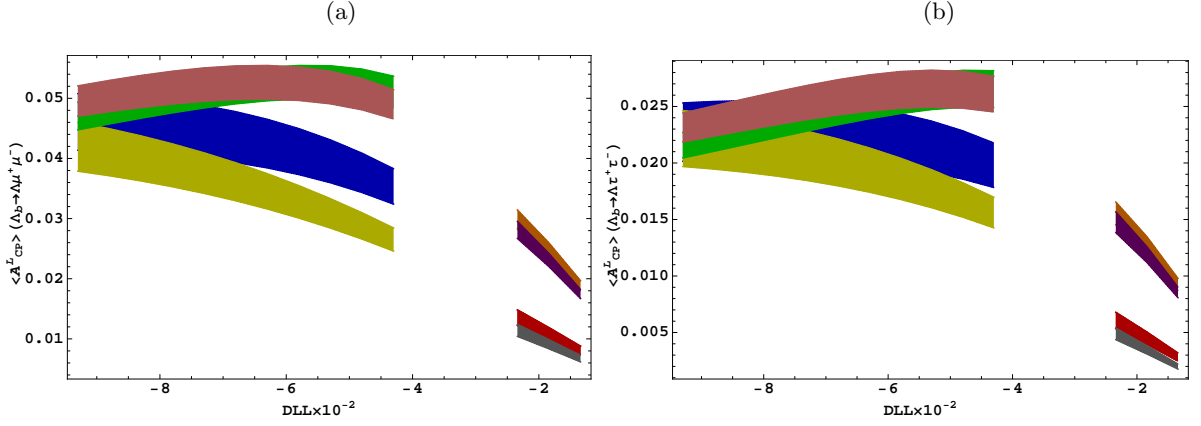


FIG. 3: Longitudinally polarized CP violation asymmetry \mathcal{A}_{CP}^L as function of D_{LL} for $\Lambda_b \rightarrow \Lambda \mu^+ \mu^- (\tau^+ \tau^-)$ for scenarios $\mathcal{S}1$, $\mathcal{S}2$ and $\mathcal{S}3$. The color and band description is same as in Fig. 1.

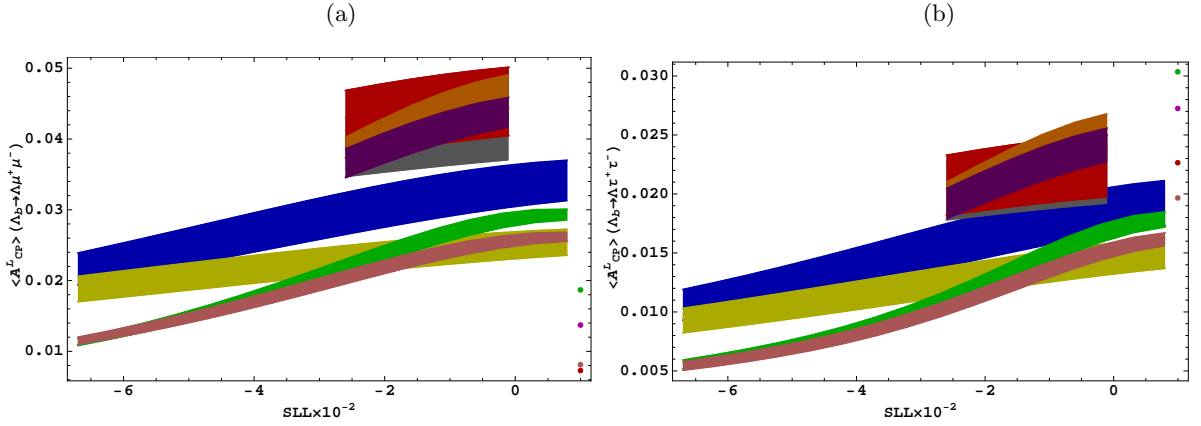


FIG. 4: Longitudinal polarized CP violation asymmetry \mathcal{A}_{CP}^L as function of S_{LL} for $\Lambda_b \rightarrow \Lambda \mu^+ \mu^- (\tau^+ \tau^-)$ for scenarios $\mathcal{S}1$, $\mathcal{S}2$ and $\mathcal{S}3$. The color and band description is same as in Fig. 1.

in Figs. 6(a) and 6b. It can also be noted that average value of the \mathcal{A}_{CP}^N increases from 0.020 to 0.045 in $\mathcal{S}1$ and 0.035 to 0.05 in $\mathcal{S}2$.

What comes out to be more interesting is the impact of parametric space of scenario $\mathcal{S}3$ in case of μ 's and final state leptons. In this scenario, the value of the normal CP violation asymmetry in $\Lambda_b \rightarrow \Lambda \mu^+ \mu^-$ is an order of magnitude larger than the corresponding values in $\mathcal{S}1$ and $\mathcal{S}2$. Here, the maximum value is 0.018 (the green dot) when $\phi_{sb} = -140^\circ$ and $|\mathcal{B}_{sb}| = 5 \times 10^{-3}$. While in case of τ 's as final state leptons the order of asymmetries remains the same as in $\mathcal{S}1$ and $\mathcal{S}2$.

Transverse polarized CP violation asymmetry:

- Just like the normal polarized CP violation asymmetry, the different terms in transverse polarized CP violation asymmetry \mathcal{A}_{CP}^T are also m_l suppressed which is visible from \mathcal{H} 's appearing in the function \mathcal{Q}^T in Eq. (40). The graphs given in Figs. 7(a) and 8(a) depict the fact that in the presence of NP, the maximum value of \mathcal{A}_{CP}^T is around 0.016 (shown by the green band) in $\Lambda_b \rightarrow \Lambda \mu^+ \mu^-$, while Figs. 7(b) and 8(b) are shown that in case of the τ 's as final state leptons the value of the \mathcal{A}_{CP}^T reaches upto 0.08 in certain parametric space of the Z' scenario $\mathcal{S}1$.

By varying the Z' parameters in the range given in Eq. (51) the trend of transverse CP violation asymmetry is shown by different colors of dots in Fig.8. In case of μ 's as final state leptons, we can see that for $\phi_{sb} = -140^\circ$, $|\mathcal{B}_{sb}| = 5 \times 10^{-3}$ in scenario $\mathcal{S}3$ the value of transverse polarized CP violation asymmetry is slightly higher than the first two scenarios (shown by the green dot). However, in $\Lambda_b \rightarrow \Lambda \tau^+ \tau^-$ decay the effects coming through the parametric space of $\mathcal{S}3$ are smaller than that of the first two scenarios.

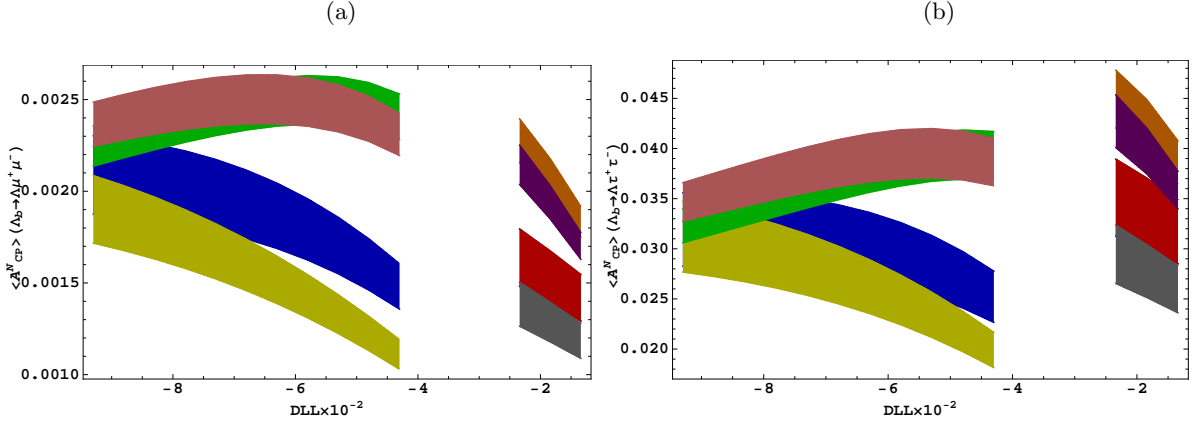


FIG. 5: Normal polarized CP violation asymmetry \mathcal{A}_{CP}^N as function of D_{LL} for $\Lambda_b \rightarrow \Lambda \mu^+ \mu^- (\tau^+ \tau^-)$ for scenarios $S1$, $S2$ and $S3$. The color and band description is same as in Fig. 1.

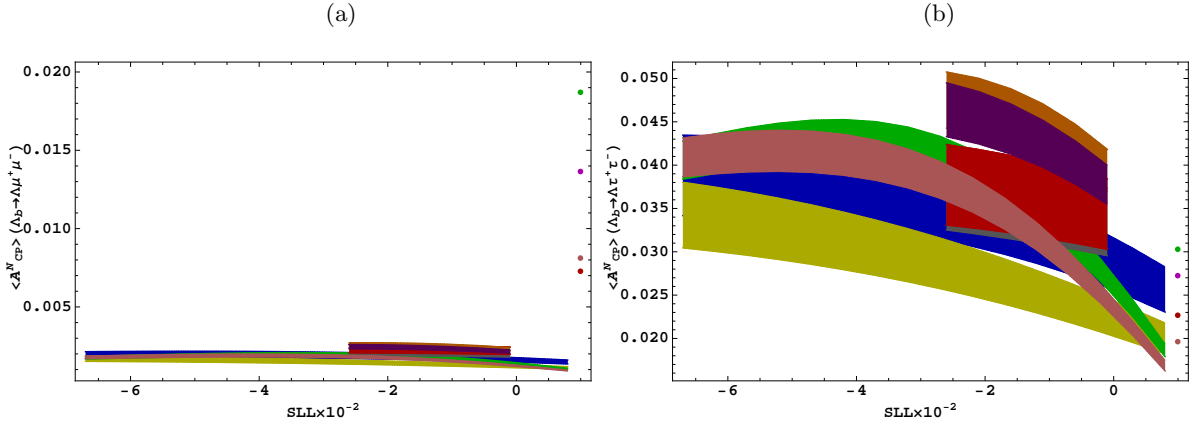


FIG. 6: Normal polarized CP violation asymmetry \mathcal{A}_{CP}^N as function of S_{LL} for $\Lambda_b \rightarrow \Lambda \mu^+ \mu^- (\tau^+ \tau^-)$ for scenarios $S1$, $S2$ and $S3$. The color and band description is same as in Fig. 1.

In short, we have analyzed the imprints of NP coming through the neutral Z' boson on the unpolarized and polarized CP violation asymmetries in $\Lambda_b \rightarrow \Lambda \ell^+ \ell^-$ decays. In addition motivated by the fact that the CP violation asymmetry is negligible in the SM, we have chosen this observable to explore the effects of Z' in $\Lambda_b \rightarrow \Lambda \ell^+ \ell^-$ decays. It has been noticed that the value of unpolarized and polarized CP violation asymmetry is considerable in both $\Lambda_b \rightarrow \Lambda \mu^+ \mu^-$ and $\Lambda_b \rightarrow \Lambda \tau^+ \tau^-$ channels and hence it gives a clear message of NP arising from the neutral Z' boson. Though the detection of leptons' polarization effects in semileptonic decays is really a daunting task at the experiments such as the ATLAS, CMS and at LHCb, but the fact that these CP violation asymmetries which suffer less from hadronic uncertainties provide a useful probe to establish the NP coming through the Z' model.

Acknowledgments

The author M. J. A would like to thank the support by Quaid-i-Azam University through the University Research Fund. M. A. P. and I. A. would like to acknowledge the grants (2012/13047-2) and (2013/23177-3) from FAPESP.

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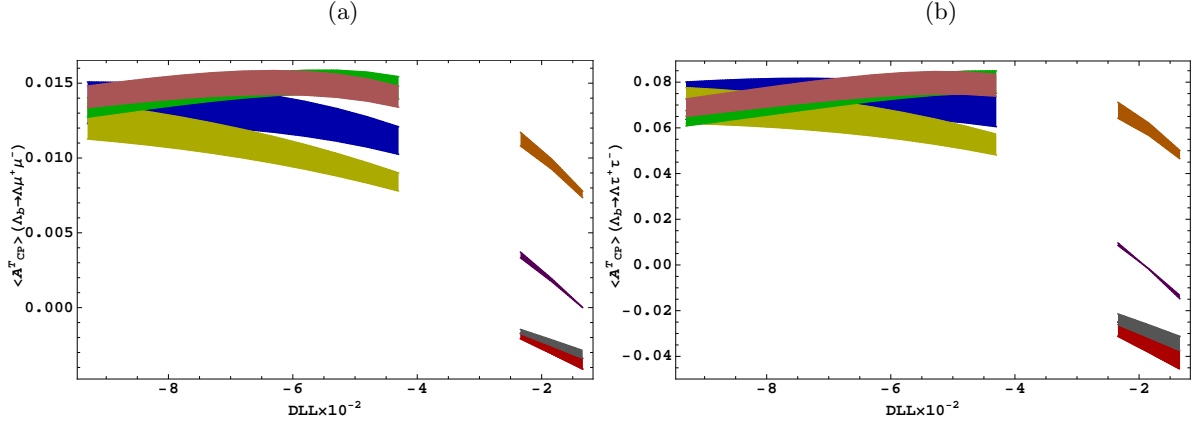


FIG. 7: Transversally polarized CP violation asymmetry \mathcal{A}_{CP}^T as function of D_{LL} for $\Lambda_b \rightarrow \Lambda \mu^+ \mu^- (\tau^+ \tau^-)$ for scenarios $S1$, $S2$ and $S3$. The color and band description is same as in Fig. 1.

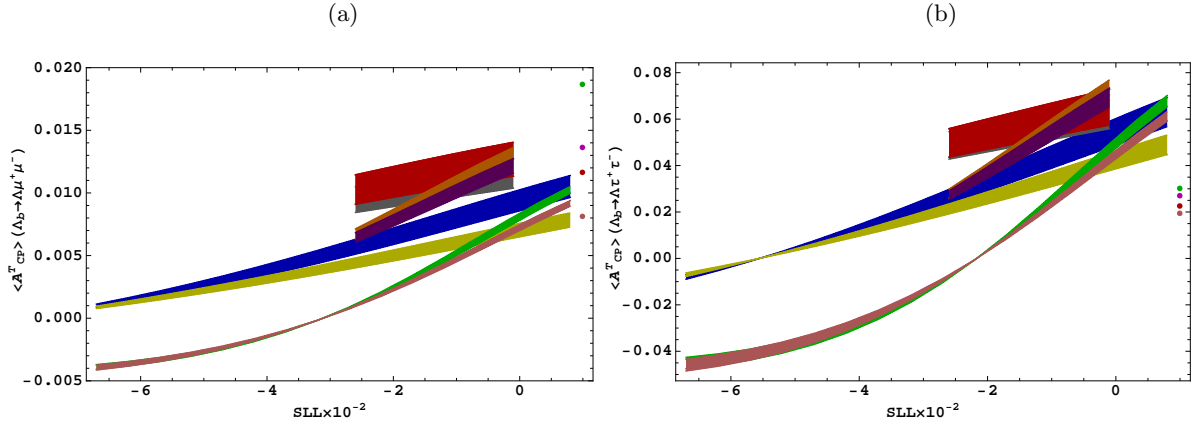


FIG. 8: Transversally polarized CP violation asymmetry \mathcal{A}_{CP}^T as function of S_{LL} for $\Lambda_b \rightarrow \Lambda \mu^+ \mu^- (\tau^+ \tau^-)$ for scenarios $S1$, $S2$ and $S3$. The color and band description is same as in Fig. 1.

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